Appendix K. Laboratory Analysis of Cementing Operations on the Deepwater Horizon (from CSI Technologies)

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Laboratory Analysis of Cementing Operations on the Deepwater Horizon

CLS0733

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Objective

The objective of this phase of the project was to investigate the performance of the Halliburton Energy Services (HES) cement system used on the Macondo casing cement job. Testing involved evaluating both an unfoamed base slurry and a foamed slurry. Slurries were foamed at atmospheric pressure and also at 1000 psi pressure.

Introduction and Background

The conventional testing of foam cement slurries in the laboratory cannot mimic the exact conditions that foam cement experiences in the well. Such is the case with the Macondo well in question. The cement job on the Macondo well used foam cement, but before and after the foam, a volume of unfoamed cement slurry was used. The volume ahead is referred to as the "cap cement", while the cement slurry behind is referred to as the "tail cement". Once the cap slurry was pumped, the foam cement was generated at the surface at nominal conditions of 100°F and 1000 psi by injecting high-pressure nitrogen into the flow line via jets incorporated into a device called a nitrogen injector head. The foamed cement then entered the well and was pumped from the surface into place some 18,000 feet below.

The unfoamed or base cement slurry for the well in question was mixed at the surface to a density of 16.74 ppg and then foamed with nitrogen at a pressure of 2000 psi. The injection of the nitrogen into the flowing slurry requires a pressure drop across injection ports in the nitrogen injector head to promote stable, well dispersed nitrogen bubbles throughout the cement slurry. The differential pressure used on the Macondo job was 1000 psi. This means that the cement slurry that received the nitrogen was being pumped at roughly 1000 psi injection pressure. The amount of unfoamed cement slurry that was pumped into the well was 38 bbls. The amount of nitrogen that was injected at the surface under 1000 psi was approximately 60 bbls at an injection temperature of 110°F. This resulted in a surface-foamed cement density of about 6.5 ppg or a foam quality (that is the % by volume of nitrogen to total slurry volume) of 55% to 60%. In-place conditions for this cement downhole were nominally 13,000 psi and 140°F. The final foam quality at these conditions was about 18.5% with a density of 14.55 ppg. The amount of nitrogen at in place conditions was about 8.5 bbls.

It is very difficult to test foam cements at surface conditions, let alone testing at downhole temperature and pressure conditions. This difficulty stems from the compressible nature of the gas phase of the foamed slurry. The PVT (Pressure, Volume, and Temperature) behavior of the gas component requires constant consideration of foam density or quality as temperature and pressure vary. A foam generated to a specified quality at a specified pressure will reduce roughly 50% in foam quality with a doubling in pressure. Temperature affects foam quality in a similar manner with increasing temperature resulting in increasing foam quality. Thus, generation of foamed cement in the lab and subsequent measurement of mechanical and performance properties require attention to generation, curing, and test conditions of the unset material.

An additional issue encountered in testing foam cements in the lab is the stability of the foam once generated. API specifies methods for generating a foam with a modified high-shear laboratory blender. The stability of the foam (i.e. how hard is it to force the bubbles to break out of the cement slurry) is indicated by the time required to generate the foam in the lab blender. A passing system should be able to be generated in 15 seconds or less in the lab blender. API recommends redesigning cements that are difficult to foam in the allotted 15 second mix time to produce base cement slurries that are more easily foamed.

Generally, two conditions are used in laboratory testing of cement slurry used for foam cement. First, the base slurry is tested for thickening time, fluid loss, free fluid, and rheology. Secondly, the laboratory generates a foam using the base cement at atmospheric pressure at the in-place foam quality. This cement is tested for foam stability tests and compressive strength development. This lab foam generation, referenced in discussion of API specifications above, has all cement slurry components and is added to the high-shear blender and mixed at high speed to incorporate foam into the cement to the desired foam quality and density. The foam stability tests are used to determine the ability of the foam cement to remain stable once mixed and not allow separation of the cement and gas. Typically these tests are conducted for several hours and visual inspections of the samples reveal separation. It is important that the generation of foam be conducted at the injection temperature expected on the job. It is also important to measure the stability of the foam at the bottom hole temperature expected once the cement slurry is placed.

On the well in question, the quality and density of the foamed cement slurry at the surface were 60% quality foam and about 6.5 ppg. It is important to test this surface-mix foam quality stability as well as the lower foam quality at in-place conditions. If the foamed cement slurry is not stable with the high amount of nitrogen at the surface injection conditions, then obviously it will not be stable at downhole conditions. It is also important to generate the foam cement at injection temperatures. The temperature of the slurry and rheology of the cement slurry to be foamed are very important in the stability of the foam cement. If a foam is created at room temperature and allowed to set under elevated temperature the cement slurry will expand and alter density and foam quality. This prevents evaluation of stability of a foam generated at one temperature then heated or cooled to another to cure.

When considering the stability of the foam cement system it is also important to test the affects contamination of various fluids or materials on the foamed slurry. Several materials used in association with placing the cement the Macondo well are possible de-stabilizers of foam quality. First, the base oil used in the mud system and ahead of the spacer could significantly destabilize the foam cement. Secondly the spacer system used can also be detrimental. The surfactants used in the Tuned III spacer (the one that was used in the Macondo well) can also destabilize the foam cement.

The Halliburton additives were not available for use in this project. Alternative additives sold as being similar in form and function the Halliburton additives were used to simulate the HES composition. This simulated HES slurry will be referred to as the Simulated HES (SIM) slurry.

Conclusions

1. CSI was able to develop a cement slurry that was similar to the Halliburton base slurry used on the Macondo well with respect to Rheology and Thickening Time. Rheology and Thickening Time data were available from the HES lab report dated April 12th, 2010.

2. The Fluid Loss of the base SIM slurry was 302cc/30min. This value was far outside the recommended fluid loss requirement of 50cc/30 min accepted by the industry for gas-migration-control cement designs.

3. The SIM base slurry could not be foamed with a single blade assembly at above 50% quality foam under atmospheric pressure at 110°F and 140°F.

4. The 18.5% quality foam was not stable when generated at atmospheric pressure at 110°F or 140°F.

5. The SIM base slurry was able to be foamed with a multi blade assembly at above 50% quality foam, but was unstable under atmospheric pressure at both 110°F and 140°F.

6. A cement slurry consisting of only Lafarge Class H cement plus foamer and water produced stable foams at foam qualities ranging from 5% to 60% quality and was stable at both 110°F and 140°F under atmospheric conditions. This system was not indicative of the slurry used on the Macondo well. It was used for comparative purposes only.

7. All of the additives used in the SIM slurry design affected both the ability to make a foam slurry as well as the resulting foam stability of the cement slurry. The KCl, Defoamer, Bulk Flow Enhancer, and Retarder all had a negative effect on the foam stability while the antisettling material had a positive effect on the foam stability.

8. The yield point of the HES designed base slurry was too low at 135°F (2 lb/100ft^2 yield point). The yield point is a significant factor in the generation and stability of foamed cements. The higher the yield point, the more stable the slurry will be. Yield points of over 5 are recommended for foam slurries.

9. Base oil contamination of 5%, 10%, and 15% of the Class H and foamer slurry and the SIM slurry made no difference in the ability to generate a foam quality from 5% to 60%. It did however cause some instability in the slurries and set samples of cement. Contamination of various well fluids can have an effect on the generation and stability of foamed cements.

10. The foamed cement slurries generated at 1000psi and cured under 1000 psi showed similar results to analogous foam cements generated and cured at atmospheric pressure.

Recommendations for Future Testing

The testing performed to date employed cements designed to be analogous to the HES cement pumped on the Macondo well. It is recommended that laboratory quantities of actual additives used by HES be obtained and that testing completed to date be repeated with the new materials. This testing should include evaluation of the effects of each potential contaminant on foam stability. Additionally, it is recognized that down-hole pressure of roughly 13,000 psi encountered on this well could also affect foam stability. A complete evaluation of foam stability and contaminant effects should also be performed on foams generated at 1000 psi and compressed to cure at 13,000 psi.

Summary of HES lab report

Halliburton's laboratory report on the cement slurry design for the Macondo well is shown in Appendix A at the end of this report. The slurry composition tested is provided with the details of the well conditions. The information provided is very limited and does not provide answers to many questions that need to be addressed prior to conducting a critical cementing operation in deep water. The information that was provided is the following:

1. Thickening time on the base slurry- This is normally how the lab tests are conducted. The base slurry without the nitrogen is used to conduct this test.
2. Density of the mixed slurry- The density of the unfoamed cement slurry indicated that the slurry was measured at 16.7 ppg.
3. Mixability – This is a measure of the ability of the unfoamed cement slurry to go into pumpable cement slurry. This is strictly a visual test and subjective to the observer.
4. UCA compressive strength – This provides the unfoamed cement slurry Ultrasonic Compressive Strength using the UCA device. The data provided indicates the unfoamed cement developed good compressive strength. The 12 hours compressive strength was 2301 psi.
5. Crush Compressive Strength – This test is normally done on the atmospherically foamed cement slurry at the specified foam quality in the well. Tests indicates that the slurry have zero strength in 12 and 24 hours and 1590 psi in 48 hours. The zero readings may indicate that there was no data available for that time period. It is indicated on the lab test that the slurry was conditioned for 1.5 hours.
6. FYSA Viscosity – This is a rheology device that is retrofitted to the conventional rotational viscometer. No company other than Halliburton uses this device. The industry and API do not recognize this method for measuring rheology of foam cements.
7. Non API Rheology measurements – Rheology measurements were conducted on the base cement slurry (unfoamed). These were not run according to API recommended practices. The 600 reading is not to be used in the operation of the rotational viscometer.
8. Foam mix and stability – This test is supposed to determine the time to mix the foam cement slurry as well as the stability. Unfortunately very little information is supplied with the data to determine what was performed. The slurry mixed in 8 seconds. The SG (specific gravity) was 1.8 at the top and 1.8 at the bottom. This indicated that the slurry was 15.0 ppg. The slurry was supposed to be mixed at 14.55 ppg. Either the slurry was mixed wrong or the stability of the foam cement was not acceptable. In the slurry section of the report, the Foam Quality was determined to be 13%. This is incorrect. The downhole foam quality was 18.5%. This difference is due to the density and non-ideal nature of the nitrogen at 13,000 psi.

Other than the tests shown above, no other tests were conducted. Several tests not performed are essential to insure proper design of the cementing treatment. Each of the other tests will be discussed below along with the reason why they should have been conducted:

a. Free fluid test – This test is a measure of the settling and free water of the cement slurry in question. Normally when using a foam cement slurry, the unfoamed slurry is used for this test. The slurry that Halliburton proposed had a very low rheology profile and had a YP of 2 at 140°F. This rheology is not acceptable for normal foam cement slurry designs. This free water test would demonstrate the base slurry stability issue of the slurry design.

b. BP settling test – This test also is the measure of the settling of the cement slurry in question. Again, normally the unfoamed slurry is poured into a cylinder and allowed to set at bottom hole temperature. The specimen is cut up and density is determined. Settling can be determined by the differences between the top and bottom of the set cement. This test will prove or disprove the stability of the cement slurry in question.
c. Fluid loss – Every slurry designed to prevent gas migration pumped into the well should have excellent fluid loss control. This slurry designed by Halliburton did not have any fluid loss additive in it. Typically a foam cement fluid loss is good due to the dual phase nature of it. There were, however, portions of the slurry pumped into the well that were not foamed. Both the cap slurry and the tail slurry should have been tested for fluid loss. Without fluid loss control these slurries would have been inappropriate.
d. Compatibility of spacer – On critical cement jobs and especially those with synthetic base mud as in the Macondo well, a suite of compatibility tests should have been conducted. The Tuned III spacer is mixed with various amounts of both mud and cement and the resultant rheology of the mixture is measured to determine the compatibility of the spacer. This is a critical parameter that was not tested.
e. Gel strength – When wells have a Gas Flow Potential (GFP) of more than 1 then the well becomes a potential flow situation. The gel strength device measures the transition of the cement slurry from the slurry to set state. The time that the cement develops critical gel strength is measure with the gel strength device. The MACS analyzer can be used or an SGSA machine can be used. Neither was used by Halliburton in this design.

Test Methods

The base slurry design reported by Halliburton (HES) is listed below and all test information and results reported by Halliburton are attached in appendix A:

HES Design
Lafarge Class H Cement + 0.07% EZ-FLO + 0.25% D-Air 3000 + 1.88lb/sk KCl Salt + 20% SSA-1 (Silica Flour) + 15% SSA-2 (100 mesh) + 0.2% SA-541 + 0.11gps ZoneSealant 2000 + 0.09gps SCR-100L mixed with 4.93gps Fresh Water at a density of 16.741 lb/gal.

CSI identified materials that are the best engineering substitutes for the Halliburton materials used on the cementing treatment. The design used for the lab testing presented in this document is listed below:

SIM Design
Lafarge Class H Cement + 0.07% LS-635 + 0.25% C-41P + 1.88lb/sk KCl Salt + 20% Silica Flour + 15% Silica Sand + 0.05% FSA-3 + 0.11gps PlexFoam C-7 + 0.09gps PCR-3 mixed with 4.93gps Fresh Water at a density of 16.741 lb/gal.

A chemical cross-reference table is listed in Table 1 below.

Table 1: Chemical Cross-Reference

Halliburton	CSI	Function	Concentration
Lafarge H	Lafarge H	Cement	100%bwoc
KCl	KCl	Salt	1.88 lb/sk
SSA-1 (Silica Flour)	Silica Flour	Silica Flour	20%bwoc
SSA-2 (100 Mesh)	100 Mesh	Silica Sand	15%bwoc
EZ-FLO	LS-635 (Chemplex)	Bulk Flow Enhancer	0.07%bwoc
D-Air 3000	C-41P (Chemplex)	Antifoam	0.25%bwoc
SA-541	FSA-3 (Fritz)	Antisettling	0.2%bwoc SA-541 / 0.05%bwoc FSA-3
ZoneSealant 2000	Plexfoam C-7 (Chemplex)	Foamer	0.11 gps
SCR-100L	PCR-3L (Fritz)	Retarder	0.09 gps
Freshwater	Freshwater	Mix Water	4.84 gps
Total Mix Fluid	Total Mix Fluid	Total Mix Fluid	5.04 gps
Density	Density	Density	16.74 lb/gal
Yield	Yield	Yield	1.37 ft^3/sk

Foam Stability Test Method

For the foam stability tests, the slurry is mixed per API without foamer and conditioned at temperature for 20 minutes using an atmospheric consistometer. The proper amount of slurry is transferred to a foaming blender and foamer is added at this time. Blending at 12,000 rpm is performed and time to foam is recorded. The foamed slurry is transferred to a graduated cylinder and a mark is placed on the cylinder to observe for any volume loss over time. The cylinder is placed in a water bath set to test temperature. The volume is measured every hour for 4 hours. If the system is stable, the set column after 48hrs is cut into sections and measured for density variations using Archimedes principle. This is performed by first measuring the weight of the section. The section is then placed in a very thin rubber sleeve and placed under a vacuum. The rubber sleeve is tied off and the section is suspended in water without touching the bottom or sides of the container of water. The weight of water displaced is equal to the volume of the specimen. The weight divided by the volume of the section equals the density of the section. For densities below the weight of water, an object of known weight and volume is attached to the section to obtain full submersion of the section. This added weight's volume is then subtracted from the total volume to obtain the proper volume of the section.

Base Oil / Cement Contamination Test Method

The base oil which was used as a spacer during operations was evaluated to see the effects on foam stability. 5, 10 and 15% by volume contaminations were created by mixing the cement systems as outlined in the foam stability test method. Once a system was foamed in the blender, the proper amount was measured into a 250mL beaker to enable addition of the proper amount of base oil. The preheated base oil is mixed into the foamed slurry by hand as to not entrain any extra air into the slurry. Testing then resumed as outlined in the foam stability test method.

1000 psi Foam Testing

The foaming cell is prepared and all transfer and nitrogen lines are put in place. This is followed by a curing vessel being prepared and placed into an oven to preheat to the testing temperature. The components of the cement slurry are then weighed and measured, and mixed in a large scale blender as per API. All components are added to the mix except for the foaming agent. The slurry is then poured into the foaming cell and closed in. It is then heated to the test temperature while stirring at approximately 150 rpm with the foam cell paddle. When the slurry in the foaming cell has reached the testing temperature, it is allowed to condition for 20 minutes, still stirring at approximately 150 revolutions per minute. After the 20 minutes has elapsed, the foaming agent is added to the conditioned slurry. The foaming cell with slurry inside is then pressurized from the bottom of the cell to 1,000psi with nitrogen and stirred at 1000 revolutions per minute for 2 minutes to induce foaming. During the two minutes, the curing vessel is removed from the oven and, in an upright position, pressurized to 1000psi with nitrogen. The curing vessel is then closed in with that 1000psi of nitrogen pressure. The transfer line from the bottom of the foaming cell is then attached to the bottom of the curing vessel. After the two minutes of foaming, the stirring is ceased and the nitrogen pressure is shut off to the bottom of the foaming cell. Nitrogen pressure at 1000psi is then introduced at the top of the foaming cell. The foamed slurry is then allowed to go into the bottom transfer line all the way to the valve at the bottom of the curing vessel. The valve at the bottom of the curing vessel is then opened and due to the pressure already in the curing vessel equaling the pressure of the foamed slurry trying to enter the cell, the foamed slurry remains in the transfer line. A valve at the top of the curing vessel is then slowly opened, releasing the nitrogen in the cell and allowing the foamed slurry to slowly enter the cell. When the cell is full of foamed slurry all the valves of the curing vessel are closed, locking in the foamed slurry at a pressure of 1000 psi. The curing vessel is then placed back into the oven at testing temperature in an upright position and allowed to cure for at least two days. After the two days, the valves are slightly opened on the curing vessel and the pressure is allowed to slowly escape the cured foamed cement. When all the pressure has been released, the curing vessel is taken apart and the cured foamed cement inside is cored out and the density of the top, middle, and bottom is measured. From those densities, the foam quality can be determined.

Base Slurry Test Results

Thickening time tests were conducted at conditions; heat to BHCT of 135 °F and BHP of 14,458 psi in 83 minutes as supplied by HES lab report. The reported thickening time of the HES base slurry with 0.09 gps SCR-100L was longer than the SIM base slurry thickening time with 0.09 gps PCR-3L, so several other retarder concentrations were tested for the SIM base slurry. All thickening time results are reported below in Table 2.

Table 2: BHCT Thickening Time Test Results of SIM and HES Base Slurry

Thickening Time	30 Bc	40 Bc	50 Bc	70 Bc	Retarder
HES*	7:25	7:34	7:36	7:37	0.09 gps SCR-100L
SIM	2:30	2:33	2:34	2:36	0.07 gps PCR-3L
SIM	3:05	3:10	3:12	3:15	0.09 gps PCR-3L
SIM	8:04	8:09	8:12	8:15	0.12 gps PCR-3L
SIM	9:18	9:20	9:21	9:23	0.13 gps PCR-3L
SIM	11:30	11:41	11:42	11:46	0.14 gps PCR-3L
SIM	14:51	14:55	14:58	15:10	0.17 gps PCR-3L

*As reported by HES lab report in Appendix A

Unless otherwise noted, retarder concentration of the SIM base slurry was 0.09 gps PCR-3. This was done to keep the same water to solids ratio between the HES and SIM cement systems.

Slurry Rheology was evaluated after base slurry was mixed, 80 °F results, and after the slurry was conditioned at estimated BHCT for 20 minutes, 135 °F results, for both SIM and HES base slurry formulation. The SIM slurry Rheology was also evaluated at the slurry injection temperature, 110 °F. The SIM base slurry is slightly more viscous than the HES base slurry. This was designed to ensure suitable slurry was utilized for the testing at CSI. The HES base slurry has low viscosity and yield point, both initially and at BHCT. This can result in an unstable base slurry. The SIM slurry was designed to have the same components as the HES base slurry, but to be more viscous; note yield point is greater than 10 for the SIM base slurry at 80°F and 135°F.

Table 3: Base Slurry Rheology Results

	80°F		110°F	135°F	
Rheology	HES	SIM	SIM	HES	SIM
600 rpm	180	320	198	130	166
300 rpm	84	164	109	56	90
200 rpm	56	118	76	40	66
100 rpm	28	66	41	20	39
60 rpm	26	43	25	12	26
30 rpm	8	24	13	8	17
6 rpm	2	8	5	4	11
3 rpm	2	5	4	2	9
PV	80	155	106	55	81
YP	4	13	4	2	11

Free fluid and fluid loss tests were performed for the SIM base slurry, but these results were not reported by HES. Both the fluid loss and free fluid were performed after conditioning the slurry at BHCT of 135 °F for 20-minutes. The free fluid for the SIM base slurry was 0%, which indicates that the slurry is stable. The fluid loss result for the base slurry was high (302 cc/30min), but that was expected as there was no fluid loss additive run in the cement systems. The SIM base slurry was foamed to 18.5% foam quality under 1000psi nitrogen pressure and obtained a fluid loss value of 66 cc/30min. The results for each are shown below in Table 4.

Table 4: Fluid Loss and Free Fluid Results for the SIM Base Slurry

Free Fluid	135°F
Test Angle	Vertical
HES	NA
SIM	0%

Fluid Loss	135°F
Pressure	1000 psi
HES	NA
SIM	302
SIM foamed	66

A static settling test was performed on the SIM base slurry at the estimated BHST of 210°F. The results indicate that the slurry has a very slight amount of solids settling, but is considered stable at just a 1.8% variance in density from top to bottom. The results are shown below in Table 5. There are no results for the HES base slurry as there were none reported.

Table 5: Static Settling Test Results for SIM Base Slurry

BP Settling 210°F	Density lb/gal
Design	16.741
Top	16.6
Middle	16.6
Bottom	16.9
Variance (%)	1.8

Foam Stability Test Results

A large matrix of foam stability tests were conducted at both the slurry injection temperature of 110°F and the CSI estimated BHCT of 140°F. The foam slurries were generated and the foam stability tests were conducted per ISO 10426-4 guidelines. These guidelines allow for use of a blender with a single mixing blade or the multi-blade (stacked blade) assembly. Testing at CSI was conducted using both blade assemblies. The test results are for slurries mixed with a single blade assembly unless otherwise noted.

For the foam stability testing, the slurry was foamed and stability tests were conducted at foam qualities ranging from 5% to 60%. 60% foam quality is important because that is the foam quality needed to generate at atmospheric conditions in order to achieve a 14.5 lb/gal slurry at bottom-hole conditions. Another key foam quality is 18.5%; this is the foam quality at bottom-hole conditions.

All subsequent tables are highlighted in green for a passing result, and red for a failing result. Any time to foam under 15 seconds is considered acceptable, over 15 seconds is unacceptable. The stability tests are shaded in green and red for ease of seeing passing and failing results. The foam qualities of 18.5% and 60% are listed in bold for easier viewing.

The foam stability results for the SIM baseline foamed system are listed below in tables 6 and 7 (110°F and 140°F respectively).

The 25%, 40%, 45%, and 50% quality foams were all stable at 110 °F under atmospheric pressure as shown in Table 6 below. However, note that the time to foam is greater than the ISO/API recommended

15 seconds for foam qualities above 20%. Also note that 55% and 60% quality foams could not be generated.

Table 6: SIM Base Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2 sec	186	24.7%	24.7%	24.7%	24.7%				15.9
10.0%	10 sec	184	29.3%	29.3%	30.4%	30.4%				15.06
18.5%	**7 sec**	**212**	**30.2%**	**30.2%**	**30.2%**	**30.2%**				**13.64**
20.0%	20 sec	210	29.5%	29.5%	29.5%	29.5%				13.38
25.0%	20 sec	210	0.0%	0.0%	0.0%	0.0%	11.8	12.1	11.7	12.55
30.0%	18 sec	190	37.9%	37.9%	37.9%	37.9%				11.72
35.0%	30 sec	210	9.5%	28.6%	36.2%	36.2%				10.88
35%(repeat)	35 sec	210	36.2%	36.2%	36.2%	36.2%				10.88
35% (.12 PCR3L	30 sec	190	28.4%	28.4%	42.1%	42.1%				10.88
40.0%	40 sec	210	0.0%	0.0%	0.0%	0.0%	9.5	9.6	9.5	10.04
45.0%	50 sec	180	0.0%	0.0%	0.0%	0.0%	10.1	9.9	9.9	9.2
50.0%	60 sec	190	0.0%	0.0%	0.0%	0.0%	9.8	9.9	9.7	8.37
55.0%	unable to fully foam									7.53
60.0%	**unable to fully foam**									**6.7**

The 5%, 25%, 45%, and 50% quality foams were all stable at 140°F and atmospheric pressure as shown in Table 7 below. However, note that the time to foam is greater than the ISO/API recommended 15 seconds for foam qualities above 20%. Also note that 55% and 60% quality foams could not be generated.

Table 7: SIM Base Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2 sec	250	0.0%	0.0%	0.0%	0.0%				15.9
10.0%	2 sec	250	24.0%	28.0%	30.4%	32.0%				15.06
18.5%	**6 sec**	**210**	**37.1%**	**37.1%**	**37.1%**	**37.1%**				**13.64**
20.0%	17 sec	210	37.1%	37.1%	37.1%	37.1%				13.38
25.0%	10 sec	210	1.0%	1.0%	1.0%	1.0%	10.4	11.9	14.1	12.55
30.0%	18 sec	196	36.7%	36.7%	35.7%	35.7%				11.72
35.0%	20 sec	210	38.1%	38.1%	38.1%	38.1%				10.88
35%(repeat)	18 sec	210	42.9%	42.9%	42.9%	42.9%				10.88
35%(add shear)	60 sec	210	45.7%	45.7%	45.7%	45.7%				10.88
40.0%	40 sec	224	47.3%	47.3%	47.3%	47.3%				10.04
40.0%	50 sec	244	42.6%	45.9%	45.9%	45.9%				10.04
45.0%	50 sec	180	0.0%	0.0%	0.0%	0.0%	10.4	10.2	10.3	9.2
50.0%	60 sec	174	0.0%	0.0%	0.0%	0.0%	10.6	10.7	10.5	8.37
55.0%	unable to fully foam									7.53
60.0%	**unable to fully foam**									**6.7**

Rheology Comparison

A study was conducted to determine the affect of each additive in the cement system has on the base, un-foamed slurry rheology. Rheology was measured at initial mix conditions 80°F, slurry injection temperature 110°F, and HES estimated BHCT 135°F. HES slurry is less viscous than the SIM slurry. The KCl, anti-foam, retarder, and bulk flow enhancer additives all seem to reduce slurry viscosity. The anti-settling additive does increase viscosity slightly. The base slurry rheology results are listed below in Tables 8, 9, and 10.

Table 8: Initial, 80°F Rheology Comparison

	Temp.	600 rpm	300 rpm	200 rpm	100 rpm	60 rpm	30 rpm	6 rpm	3 rpm	PV	YP
HES	80°F	180	84	56	28	26	8	2	2	80	4
SIM	80°F	320	164	118	66	43	24	8	5	155	13
H, Foamer	80°F	106	58	44	26	18	12	8	6	51	9
H, Foamer, Retarder	80°F	66	34	26	16	12	8	6	4	29	6
H, Foamer, Antifoam	80°F	98	56	40	26	18	12	8	6	48	9
H,SF,SS,Foamer,KCl	80°F	202	122	100	74	62	48	26	18	80	47
H,SF,SS,Foamer,KCl,Retarder	80°F	102	82	58	32	20	12	8	4	78	5
H,SF,SS,Foamer,KCl,Retarder,Antifoam	80°F	126	66	46	24	18	10	6	4	62	5
H,SF,SS,Foamer,KCl,Retarder,Antifoam,Bulk Flow Enhancer	80°F	122	68	46	26	16	10	6	4	64	4

Table 9: 110°F Rheology Comparison

HES	110°F	na	na	na	na	na	na	na	na	na	na
SIM	110°F	198	109	76	41	25	13	5	4	106	4
H, Foamer	110°F	74	40	30	20	16	12	10	8	31	10
H, Foamer, Retarder	110°F	48	26	20	12	10	8	6	4	20	6
H, Foamer, Antifoam	110°F	62	32	24	16	12	10	8	6	25	8
H,SF,SS,Foamer,KCl	110°F	86	56	40	24	18	14	10	8	47	9
H,SF,SS,Foamer,KCl,Retarder	110°F	70	34	26	16	12	10	8	6	27	7
H,SF,SS,Foamer,KCl,Retarder,Antifoam	110°F	56	32	22	14	12	8	6	4	26	6
H,SF,SS,Foamer,KCl,Retarder,Antifoam,Bulk Flow Enhancer	110°F	64	32	22	12	10	8	6	4	27	5

Table 10: 135°F Rheology Comparison

HES	135°F	130	56	40	20	12	8	4	2	55	2
SIM	135°F	166	90	66	39	26	17	11	9	81	11
H, Foamer	135°F	74	56	46	40	36	30	22	18	27	31
H, Foamer, Retarder	135°F	50	30	22	14	10	8	6	4	25	6
H, Foamer, Antifoam	135°F	64	42	32	22	20	16	12	10	28	14
H,SF,SS,Foamer,KCl	135°F	136	90	76	60	52	42	22	16	51	43
H,SF,SS,Foamer,KCl,Retarder	135°F	62	34	22	12	10	8	6	4	29	4
H,SF,SS,Foamer,KCl,Retarder,Antifoam	135°F	46	32	22	14	12	8	6	4	26	6
H,SF,SS,Foamer,KCl,Retarder,Antifoam,Bulk Flow Enhancer	135°F	56	30	20	12	10	8	6	4	24	5

Appendix B lists further testing which includes foam stabilities, single vs. multi blade comparison, base oil contaminations, and 1000 psi foam generation tests.

Appendix A

HES lab report

HALLIBURTON

Cementing Gulf of Mexico, Broussard

LAB RESULTS - Primary

Job Information

Request/Slurry	73909/2	**Rig Name**	TRANSOCEAN HORIZON	**Date**	April 12th 2010
Submitted By	Jesse Gagliano	**Job Type**	9 7/8" X 7" Prod Casing	**Bulk Plant**	Fourchon-C-Port I, La, USA
Customer	BP	**Location**	Mississippi Cny	**Well**	Mississippi Canyon 252 OCS-G-32306 Macondo #1

Well Information

Casing/Liner Size	7"	**Depth MD**	18360 ft	**BHST**	210 F
Hole Size	9 7/8"	**Depth TVD**	18360 ft	**BHCT**	135 F

Drilling Fluid Information

Mud Company	MI	**Type**	SOBM	**Density**	14,1 PPG	**PV/YP**

Cement Information - Primary Design

Conc	UOM	Cement/Additive	Sample Type	Sample Date	Lot No.
100.00	% BWOC	Lafarge Class H	Rig	Apr 05, 2010	Tank # 8
0.07	% BWOC	EZ-FLO	Rig	Apr 05, 2010	
0.25	% BWOC	D-Air 3000	Rig	Apr 05, 2010	
1.88	lb/sk	KCl (Potassium Chloride) Salt	Rig	Apr 05, 2010	
20.00	% BWOC	SSA-1 (Silica Flour) - PB	Rig	Apr 05, 2010	
15.00	% BWOC	SSA-2 (100 Mesh) - PB	Rig	Apr 05, 2010	
0.20	% BWOC	SA-541	Rig	Apr 05, 2010	
0.11	gps	ZoneSealant 2000	Lab	Mar 15, 2009	
0.09	gps	SCR-100L	Lab	Oct 22, 2009	6264
4.93	gps	Fresh Water	Lab	Apr 12, 2010	FRESH WATER

Cement Properties

Slurry Density	16.741	PPG
Slurry Yield	1.37	FT3
Water Requirement	4.93	GPS
Total Mix Fluid	5.02	GPS
Foam Density	14.496	PPG
Foam Quality	12.98	%
Water Source	Fresh Water	
Water Chloride	N/A	ppm

Operation Test Results Request ID 73909/2

Thickening Time, Request Test ID:812338

Temp (°F)	Pressure (psi)	Reached in (min)	Start BC	30 Bc (hh:mm)	40 Bc (hh:mm)	50 Bc (hh:mm)	70 Bc (hh:mm)
135	14,458	83	14	07:25	07:34	07:36	07:37

Mud Balance Density, Request Test ID:811529

Density (ppg)

16.7

from part 1

Mixability (0 - 5) - 0 is not mixable, Request Test ID:811524

Mixability rating (0 - 5)

4

UCA Comp. Strength, Request Test ID:811522

End Temp (°F)	Pressure (psi)	50 psi (hh:mm)	500 psi (hh:mm)	12 hr CS (psi)	24 hr CS (psi)	48 hr CS (psi)
210	14,458	08:12	08:40	2,301	2,966	3,099

Circulate before pouring C.S. for 3 Hrs

Operation Test Results Request ID 73909/1

Crush Compressive Strength, Request Test ID:806069

Curing Temp (°F)	Time 1 (hrs)	Strength 1	Time 2 (hrs)	Strength 2	Time 3 (hrs)	Strength 3	Foam quality
180	12	0	24	0	48	1,590	0

Condition for 1.5 hrs

FYSA Viscosity Profile & Gel Strength, Request Test ID:806074

Test Temp (°F)
80

600=14, 300=7, 200=5, 100=3, 60=1, 30=1, 6=1, 3=1.... 6D=1, 3D=1

Non API Rheology, Request Test ID:806075

Test temp (°F)	600	300	200	100	60	30	20	10	6	3
80	180	84	56	28	26	8	6	4	2	2

Non API Rheology, Request Test ID:806076

Test temp (°F)	600	300	200	100	60	30	20	10	6	3
135	130	56	40	20	12	8	6	4	4	2

Foam Mix and Stability, Request Test ID:813603

Time to Foam [Sec]	SG top	SG bot.	Conditioning time (hrs:min)
8	1.8	1.8	03:00

Appendix B

Effect of Various Additives on Foam Stability, Multi Blade vs Single Blade Assembly Comparison, Foam Stability of Base Oil / Cement Contamination, 1000psi Foam Stability

Effect of Various Additives on Foam Stability

The foam stability results for the SIM baseline foamed system, minus the anti-foam (C-41P) are listed below in tables 11 and 12 (110°F and 140°F respectively).

All foam qualities were unstable at 110°F and atmospheric pressure as shown in Table 11 below. Also, note that the time to foam is greater than the ISO/API recommended 15 seconds for foam qualities above 45%. Finally, note that 60% quality foam could not be generated.

Table 11: SIM Base (minus anti-foam) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	3 sec	214	11.2%	11.2%	11.2%	11.2%				15.9
10.0%	3 sec	210	14.3%	14.3%	14.3%	14.3%				15.06
18.5%	**3 sec**	**210**	**28.6%**	**28.6%**	**28.6%**	**28.6%**				**13.64**
20.0%	4 sec	210	31.9%	31.9%	31.9%	31.9%				13.38
25.0%	4 sec	210	34.3%	39.0%	39.0%	39.0%				12.55
30.0%	10 sec	150	18.7%	34.7%	38.7%	38.7%				11.72
35.0%	14 sec	164	40.2%	48.8%	48.8%	48.8%				10.88
40.0%	13 sec	162	44.4%	50.6%	50.6%	50.6%				10.04
45.0%	29 sec	166	56.6%	56.6%	56.6%	56.6%				9.2
50.0%	30 sec	180	0.0%	58.9%	58.9%	58.9%				8.37
55.0%	40 sec	190	63.2%	63.2%	63.2%	63.2%				7.53
60.0%	**unable to foam**									**6.7**

All foam qualities were unstable at 140°F and atmospheric pressure as shown in Table 9 below. Also, note that the time to foam is greater than the ISO/API recommended 15 seconds for foam qualities above 45%. Finally, note that 60% quality foam could not be generated.

Table 12: SIM Base (minus anti-foam) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F			Foam Stability Test (%lost)				Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2 sec	206	27.2%	27.2%	27.2%	27.2%				15.9
10.0%	3 sec	210	23.8%	23.8%	23.8%	23.8%				15.06
18.5%	**3 sec**	**210**	**31.4%**	**31.4%**	**31.4%**	**31.4%**				**13.64**
20.0%	3 sec	210	38.1%	38.1%	38.1%	38.1%				13.38
25.0%	3 sec	210	36.2%	36.2%	40.0%	40.0%				12.55
30.0%	10 sec	157	5.7%	17.2%	17.2%	17.2%				11.72
35.0%	12 sec	162	39.5%	48.1%	49.4%	49.4%				10.88
40.0%	12 sec	168	49.4%	50.0%	51.2%	51.2%				10.04
45.0%	16 sec	164	57.3%	57.3%	57.3%	57.3%				9.2
50.0%	35 sec	204	57.8%	57.8%	57.8%	57.8%				8.37
55.0%	40 sec	204	60.8%	61.8%	62.7%	62.7%				7.53
60.0%	unable to foam									**6.7**

Due to the instability seen in the first set of testing, a new matrix of tests was conducted looking at the effects of each particular additive on slurry stability. The first set of data was with just class H cement and foamer at 110 °F and 140 °F and atmospheric pressure. These results are shown below in tables 13 and 14. Note that all foam qualities were stable at both temperatures. Also, the time to foam was less than ISO/API recommended 15 seconds for all foam qualities.

Table 13: Class H and Foamer Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F			Foam Stability Test (%lost)				Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2	200	0.0%	0.0%	0.0%	0.0%	15.8	15.9	15.9	15.57
10.0%	1	210	0.0%	0.0%	0.0%	0.0%	14.9	15	15	14.75
18.5%	**2**	**182**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.6**	**13.36**
20.0%	3	210	0.0%	0.0%	0.0%	0.0%	13.1	13.2	13.3	13.12
25.0%	3	210	0.0%	0.0%	0.0%	0.0%	12.4	12.5	12.6	12.3
30.0%	4	210	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
35.0%	4	210	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
40.0%	5	190	0.0%	0.0%	0.0%	0.0%	10	10	10	9.84
45.0%	6	210	0.0%	0.0%	0.0%	0.0%	9	9.1	9.2	9.02
50.0%	9	210	0.0%	0.0%	0.0%	0.0%	8	8.2	8.4	8.19
55.0%	11	210	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.38
60.0%	**15**	**180**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.8**	**6.56**

Table 14: Class H and Foamer Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	1	220	0.0%	0.0%	0.0%	0.0%	15.8	15.8	15.9	15.57
10.0%	1	210	0.0%	0.0%	0.0%	0.0%	15	15	15	14.75
18.5%	**2**	**210**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.6**	**13.6**	**13.6**	**13.36**
20.0%	2	210	0.0%	0.0%	0.0%	0.0%	13.1	13.2	13.4	13.12
25.0%	3	210	0.0%	0.0%	0.0%	0.0%	12.2	12.3	12.4	12.3
30.0%	3	210	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
35.0%	4	210	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
40.0%	5	210	0.0%	0.0%	0.0%	0.0%	10	10	10	9.84
45.0%	6	210	0.0%	0.0%	0.0%	0.0%	9	9.1	9.2	9.02
50.0%	7	210	0.0%	0.0%	0.0%	0.0%	8.4	8.4	8.4	8.19
55.0%	9	210	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.38
60.0%	**15**	**230**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.56**

The next set of data is the foam stability results for class H cement, foamer, and retarder at 110°F and 140°F and atmospheric pressure. These results are shown below in tables 15 and 16. Note that only 5% to 35% foam qualities were stable at both temperatures, while all foam qualities above 35% were unstable. Also, the time to foam was less than ISO/API recommended 15 seconds for all foam qualities with the exception of 55% and 60% qualities.

Table 15: Class H + Foamer + Retarder Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2	180	0.0%	0.0%	0.0%	0.0%	15.7	15.8	15.9	15.57
10.0%	2	180	0.0%	0.0%	0.0%	0.0%	14.8	15	15.2	14.75
18.5%	**2**	**180**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.2**	**13.4**	**13.6**	**13.36**
20.0%	2	180	0.0%	0.0%	0.0%	0.0%	13.2	13.4	13.5	13.12
25.0%	3	180	0.0%	0.0%	0.0%	0.0%	12.2	12.5	12.7	12.3
30.0%	4	180	0.0%	0.0%	0.0%	0.0%	11.2	11.5	11.9	11.48
35.0%	5	180	0.0%	0.0%	0.0%	0.0%	9.8	10.5	11.3	10.66
40.0%	10	190	0.0%	57.9%	57.9%	57.9%				9.84
45.0%	10	180	62.2%	62.2%	62.2%	62.2%				9.02
50.0%	11	184	62.0%	62.0%	62.0%	62.0%				8.19
55.0%	16	180	61.1%	61.1%	61.1%	61.1%				7.38
60.0%	**18**	**180**	**61.1%**	**61.1%**	**61.1%**	**61.1%**				**6.56**

Table 16: Class H + Foamer + Retarder Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam Density
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	
5.0%	2	240	0.0%	0.0%	0.0%	0.0%	15.8	15.9	15.9	15.57
10.0%	2	240	0.0%	0.0%	0.0%	0.0%	14.8	15	15.1	14.75
18.5%	**2**	**240**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.7**	**13.36**
20.0%	2	240	0.0%	0.0%	0.0%	0.0%	13.2	13.3	13.4	13.12
25.0%	3	244	0.0%	0.0%	0.0%	0.0%	12.2	12.3	12.6	12.3
30.0%	4	240	0.0%	0.0%	0.0%	0.0%	11.3	11.6	11.9	11.48
35.0%	5	240	0.0%	0.0%	0.0%	0.0%	10	10.5	11.2	10.66
40.0%	10	240	66.7%	66.7%	66.7%	66.7%				9.84
45.0%	10	240	62.5%	62.5%	62.5%	62.5%				9.02
50.0%	11	240	62.5%	62.5%	62.5%	62.5%				8.19
55.0%	16	240	66.7%	66.7%	66.7%	66.7%				7.38
60.0%	**18**	**240**	**66.7%**	**66.7%**	**66.7%**	**66.7%**				**6.56**

The next set of data is the foam stability results for class H cement, foamer, and anti-foam at 110°F and 140°F at atmospheric pressure. These results are shown below in tables 17 and 18. Note that all foam qualities were stable at both temperatures. Also, the time to foam was greater than ISO/API recommended 15 seconds for foam qualities greater than 45%.

Table 17: Class H + Foamer + Anti-Foam Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam Density
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	
5.0%	5	190	0.0%	0.0%	0.0%	0.0%	15.9	15.9	15.9	15.57
10.0%	5	190	0.0%	0.0%	0.0%	0.0%	14.9	14.9	15	14.75
18.5%	**10**	**190**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.6**	**13.36**
20.0%	10	190	0.0%	0.0%	0.0%	0.0%	13.2	13.3	13.4	13.12
25.0%	15	190	0.0%	0.0%	0.0%	0.0%	12.3	12.4	12.6	12.3
30.0%	15	190	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
35.0%	15	190	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
40.0%	15	190	0.0%	0.0%	0.0%	0.0%	9.9	9.9	10	9.84
45.0%	25	190	0.0%	0.0%	0.0%	0.0%	9.1	9.2	9.2	9.02
50.0%	25	190	0.0%	0.0%	0.0%	0.0%	8.3	8.4	8.4	8.19
55.0%	30	190	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.38
60.0%	**50**	**198**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.6**	**6.7**	**6.7**	**6.56**

Table 18: Class H + Foamer + Anti-Foam Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F										Foam
		Foam Stability Test (%lost)					Density			
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	5	245	0.0%	0.0%	0.0%	0.0%	15.8	15.9	15.9	15.57
10.0%	5	245	0.0%	0.0%	0.0%	0.0%	15	15	15.1	14.75
18.5%	**10**	**245**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.6**	**13.36**
20.0%	10	245	0.0%	0.0%	0.0%	0.0%	13.2	13.4	13.4	13.12
25.0%	10	245	0.0%	0.0%	0.0%	0.0%	12.4	12.5	12.6	12.3
30.0%	10	244	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
35.0%	10	245	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
40.0%	12	244	0.0%	0.0%	0.0%	0.0%	9.9	9.9	10	9.84
45.0%	20	240	0.0%	0.0%	0.0%	0.0%	9.1	9.2	9.2	9.02
50.0%	20	240	0.0%	0.0%	0.0%	0.0%	8.2	8.3	8.4	8.19
55.0%	25	244	0.0%	0.0%	0.0%	0.0%	7.4	7.5	7.5	7.38
60.0%	**40**	**242**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.6**	**6.7**	**6.7**	**6.56**

The next set of data is the foam stability results for class H cement, silica flour, silica sand, foamer, and anti-settling at 110°F and 140°F at atmospheric pressure for only a few of the higher foam qualities. These results are shown below in tables 19 and 20. Note that all foam qualities were stable at both temperatures. Also, the time to foam was greater than ISO/API recommended 15 seconds for all foam qualities tested. All additional foam qualities were too viscous to mix and test for these slurries.

Table 19: (Class H + Silica Sand + Silica Four +Foamer + Anti-Settling) or (SIM slurry minus KCl, Antifoam, Bulk Flow Enhancer, and Retarder) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F										Foam
		Foam Stability Test (%lost)					Density			
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
50.0%	30	194	0.0%	0.0%	0.0%	0.0%	8	8.2	8.4	8.37
55.0%	30	194	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.53
60.0%	**25**	**194**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.7**

Table 20: (Class H + Silica Sand + Silica Four +Foamer + Anti-Settling) or (SIM slurry minus KCl, Antifoam, Bulk Flow Enhancer, and Retarder) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F										Foam
		Foam Stability Test (%lost)					Density			
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
60.0%	**25**	**243**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.7**

The next set of data is the foam stability results for class H cement, silica flour, silica sand, foamer, and KCl at 110°F and 140°F at atmospheric pressure. These results are shown below in tables 21 and 22. Note that all foam qualities were stable at both temperatures. Also, the time to foam was greater than ISO/API recommended 15 seconds for all foam qualities tested.

Table 21: (Class H + Silica Sand + Silica Four +Foamer + KCl) or (SIM slurry minus Antisettling, Antifoam, Bulk Flow Enhancer, and Retarder) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	25	194	0.0%	0.0%	0.0%	0.0%	15.9	15.9	15.9	15.9
10.0%	28	196	0.0%	0.0%	0.0%	0.0%	15.1	15.1	15.1	15.06
18.5%	**25**	**194**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.6**	**13.6**	**13.6**	**13.64**
20.0%	25	194	0.0%	0.0%	0.0%	0.0%	13.2	13.3	13.4	13.38
25.0%	20	194	0.0%	0.0%	0.0%	0.0%	12.5	12.6	12.6	12.55
30.0%	15	194	0.0%	0.0%	0.0%	0.0%	11.7	11.7	11.7	11.72
35.0%	27	194	0.0%	0.0%	0.0%	0.0%	10.9	10.9	10.9	10.88
40.0%	28	194	0.0%	0.0%	0.0%	0.0%	9.9	10	10.1	10.04
45.0%	24	194	0.0%	0.0%	0.0%	0.0%	9.1	9.2	9.2	9.2
50.0%	22	194	0.0%	0.0%	0.0%	0.0%	8.3	8.3	8.4	8.37
55.0%	28	194	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.6	7.53
60.0%	**30**	**194**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.7**

Table 22: (Class H + Silica Sand + Silica Four +Foamer + KCl) or (SIM slurry minus Antisettling, Antifoam, Bulk Flow Enhancer, and Retarder) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	25	224	0.0%	0.0%	0.0%	0.0%	15.9	15.9	15.9	15.9
10.0%	28	220	0.0%	0.0%	0.0%	0.0%	15	15.1	15.1	15.06
18.5%	**25**	**224**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.6**	**13.6**	**13.6**	**13.64**
20.0%	25	224	0.0%	0.0%	0.0%	0.0%	13.4	13.4	13.4	13.38
25.0%	20	224	0.0%	0.0%	0.0%	0.0%	12.6	12.6	12.6	12.55
30.0%	20	224	0.0%	0.0%	0.0%	0.0%	11.7	11.7	11.7	11.72
35.0%	26	224	0.0%	0.0%	0.0%	0.0%	10.9	10.9	10.9	10.88
40.0%	28	224	0.0%	0.0%	0.0%	0.0%	9.9	10	10.1	10.04
45.0%	25	224	0.0%	0.0%	0.0%	0.0%	9.2	9.2	9.2	9.2
50.0%	30	225	0.0%	0.0%	0.0%	0.0%	8.2	8.3	8.4	8.37
55.0%	28	224	0.0%	0.0%	0.0%	0.0%	7.6	7.6	7.6	7.53
60.0%	**30**	**226**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.7**

The next set of data is the foam stability results for class H cement, silica flour, silica sand, foamer, KCl, and retarder at 110°F and 140°F at atmospheric pressure. These results are shown below in tables 23 and 24.

Note for the 110°F testing that all foam qualities were stable. Also, the time to foam was less than ISO/API recommended 15 seconds for all foam qualities tested except for the 60% quality.

Table 23: (Class H + Silica Sand + Silica Four +Foamer + KCl + retarder) or (SIM slurry minus Antisettling, Antifoam and Bulk Flow Enhancer) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam Density
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	
5.0%	1	160	0.0%	0.0%	0.0%	0.0%	15.9	15.9	15.9	15.9
10.0%	1	156	0.0%	0.0%	0.0%	0.0%	15	15.1	15.1	15.06
18.5%	**3**	**161**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.6**	**13.64**
20.0%	3	160	0.0%	0.0%	0.0%	0.0%	13.4	13.4	13.4	13.38
25.0%	5	160	0.0%	0.0%	0.0%	0.0%	12.5	12.6	12.6	12.55
30.0%	5	161	0.0%	0.0%	0.0%	0.0%	11.7	11.7	11.7	11.72
35.0%	5	160	0.0%	0.0%	0.0%	0.0%	10.7	10.8	10.9	10.88
40.0%	5	161	0.0%	0.0%	0.0%	0.0%	9.6	10	10.4	10.04
45.0%	10	160	0.0%	0.0%	0.0%	0.0%	8.8	9.2	9.5	9.2
50.0%	11	161	0.0%	0.0%	0.0%	0.0%	7.8	8.4	8.8	8.37
55.0%	15	160	0.0%	0.0%	0.0%	0.0%	7	7.5	8	7.53
60.0%	**20**	**224**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6**	**6.9**	**7.5**	**6.7**

Note for the 140°F at atmospheric pressure testing that foam qualities of 5% to 35% were stable, and above 35% quality was unstable. Also, the time to foam was less than ISO/API recommended 15 seconds for all foam qualities tested.

Table 24: (Class H + Silica Sand + Silica Four +Foamer + KCl + retarder) or (SIM slurry minus Antisettling, Antifoam and Bulk Flow Enhancer) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	1	240	0.0%	0.0%	0.0%	0.0%	15.9	15.9	15.9	15.9
10.0%	2	240	0.0%	0.0%	0.0%	0.0%	15.1	15.2	15.2	15.06
18.5%	**3**	**240**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.6**	**13.6**	**13.6**	**13.64**
20.0%	3	240	0.0%	0.0%	0.0%	0.0%	13.4	13.4	13.4	13.38
25.0%	4	240	0.0%	0.0%	0.0%	0.0%	12.5	12.6	12.5	12.55
30.0%	4	240	0.0%	0.0%	0.0%	0.0%	11.7	11.7	11.7	11.72
35.0%	5	240	0.0%	0.0%	0.0%	0.0%	10	10.5	11.5	10.88
40.0%	5	240	29.2%	29.2%	29.2%	29.2%				10.04
45.0%	8	240	29.2%	29.2%	29.2%	29.2%				9.2
50.0%	9	158	49.4%	49.4%	49.4%	49.4%				8.37
55.0%	12	240	29.2%	29.2%	29.2%	29.2%				7.53
60.0%	**12**	**161**	**56.5%**	**56.5%**	**56.5%**	**56.5%**				**6.7**

The next set of data is the foam stability results for class H cement, silica flour, silica sand, foamer, KCl, retarder, and anti-foam at 110°F and 140°F at atmospheric pressure. These results are shown below in tables 25 and 26.

For the 110°F stability testing, foam qualities greater than 18.5% were stable. The time to foam was greater than the ISO/API recommended time of 15 seconds for foam qualities greater than 25%.

Table 25: (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam) or (SIM slurry minus Antisettling and Bulk Flow Enhancer) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	10	190	15.8%	15.8%	15.8%	15.8%				15.9
10.0%	12	190	14.7%	14.7%	14.7%	14.7%				15.06
18.5%	**10**	**190**	**7.4%**	**7.4%**	**7.4%**	**7.4%**				**13.64**
20.0%	12	190	6.3%	6.3%	6.3%	6.3%				13.38
25.0%	16	190	0.0%	0.0%	0.0%	0.0%	12.5	12.6	12.7	12.55
30.0%	18	190	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.72
35.0%	18	190	0.0%	0.0%	0.0%	0.0%	10.8	11	11	10.88
40.0%	20	190	0.0%	0.0%	0.0%	0.0%	10	10	10	10.04
45.0%	18	190	0.0%	0.0%	0.0%	0.0%	8.8	9.2	9.5	9.2
50.0%	20	190	0.0%	0.0%	0.0%	0.0%	8.2	8.3	8.5	8.37
55.0%	30	190	0.0%	0.0%	0.0%	0.0%	7	7.5	8	7.53
60.0%	**30**	**190**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6**	**6.5**	**6.8**	**6.7**

Note that for the 140°F stability testing, all foam qualities were unstable. Foam qualities greater than 45% had a longer time to foam than the ISO/API recommended limit of 15 seconds.

Table 26: (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam) or (SIM slurry minus Antisettling and Bulk Flow Enhancer) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	10	240	25.0%	25.0%	25.0%	25.0%				15.9
10.0%	8	240	25.0%	25.0%	25.0%	25.0%				15.06
18.5%	**8**	**240**	**26.7%**	**26.7%**	**26.7%**	**26.7%**				**13.64**
20.0%	10	240	25.8%	25.8%	25.8%	25.8%				13.38
25.0%	12	240	29.2%	29.2%	29.2%	29.2%				12.55
30.0%	14	242	33.9%	33.9%	33.9%	33.9%				11.72
35.0%	12	190	47.4%	47.4%	47.4%	47.4%				10.88
40.0%	12	190	47.4%	47.4%	47.4%	47.4%				10.04
45.0%	15	190	57.9%	57.9%	57.9%	57.9%				9.2
50.0%	16	190	57.9%	57.9%	57.9%	57.9%				8.37
55.0%	40	190	53.7%	57.9%	57.9%	57.9%				7.53
60.0%	**45**	**190**	**57.9%**	**57.9%**	**57.9%**	**57.9%**				**6.7**

The next set of data is the foam stability results for class H cement, silica flour, silica sand, foamer, KCl, retarder, anti-foam, and bulk flow enhancer at 110 °F and 140 °F at atmospheric pressure. These results are shown below in tables 27 and 28. Note for the 110 °F testing that only the 25% and 55% foam qualities were stable, and all other foam qualities were unstable. The 60% quality foam could not be generated. The time to foam was greater than ISO/API recommended 15 seconds for foam qualities above 40% quality.

Table 27: (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam + Bulk Flow Enhancer) or (SIM slurry minus Antisettling) Slurry Foam Stability Results at 110°F Atmospheric Pressure (Single Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	8	190	26.3%	26.3%	26.3%	26.3%				15.57
10.0%	3	192	20.8%	20.8%	20.8%	20.8%				14.75
18.5%	**3**	**190**	**27.4%**	**27.4%**	**27.4%**	**27.4%**				**13.36**
20.0%	10	190	27.4%	27.4%	27.4%	27.4%				13.12
25.0%	10	190	0.0%	0.0%	0.0%	0.0%	8.4	15.3	16.4	12.3
30.0%	6	190	34.7%	34.7%	34.7%	34.7%				11.48
35.0%	15	190	43.2%	43.2%	43.2%	43.2%				10.66
40.0%	7	190	42.1%	42.1%	42.1%	42.1%				9.84
45.0%	20	190	50.5%	50.5%	50.5%	50.5%				9.02
50.0%	17	210	50.5%	50.5%	50.5%	50.5%				8.19
55.0%	50	190	0.0%	0.0%	0.0%	0.0%	7.4	7.5	14.4	7.38
60.0%	unable to foam									**6.56**

Note for the 140°F testing that only the 55% foam quality was stable, and all other foam qualities were unstable. Again, the 60% quality foam could not be generated. The time to foam was greater than ISO/API recommended 15 seconds for foam qualities above 40% quality.

Table 28: (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam + Bulk Flow Enhancer) or (SIM slurry minus Antisettling) Slurry Foam Stability Results at 140°F Atmospheric Pressure (Single Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	6	190	21.1%	21.1%	21.1%	21.1%				15.57
10.0%	2	190	21.1%	21.1%	21.1%	21.1%				14.75
18.5%	**3**	**194**	**24.7%**	**24.7%**	**24.7%**	**24.7%**				**13.36**
20.0%	8	190	29.5%	29.5%	29.5%	29.5%				13.12
25.0%	10	190	35.8%	35.8%	35.8%	35.8%				12.3
30.0%	4	192	34.4%	34.4%	34.4%	34.4%				11.48
35.0%	12	190	36.8%	36.8%	36.8%	36.8%				10.66
40.0%	7	190	38.9%	38.9%	38.9%	38.9%				9.84
45.0%	15	190	47.4%	47.4%	47.4%	47.4%				9.02
50.0%	11	210	55.2%	55.2%	55.2%	55.2%				8.19
55.0%	24	190	0.0%	0.0%	0.0%	0.0%	7.4	7.5	14.8	7.38
60.0%	unable to foam									**6.56**

Multi Blade vs Single Blade Assembly Comparison

ISO and API specifications allow for the use of two different types of blade assemblies for generating foam cement slurries in the laboratory. They allow for use of either a single or stacked multi blade assembly. A comparison was run to spot check various stability test results that were obtained with a single blade assembly with a multi blade assembly. The multi blade assembly has 5 blades across the height of the blender cup which imparts more shear on the cement slurry during mixing.

The first comparison data is listed below in Table 29 and 30. The test results are with the Class H, silica sand, silica flour, foamer, KCl, retarder, anti-foam, and bulk flow enhancer additive at atmospheric pressure.

Results at 110°F between the single blade and multi blade assemblies were similar at 18.5% and 60%, both were unstable. The single blade produced a stable slurry at 25% quality and the multi blade did not. The multi blade produced a stable slurry at 50% quality and the single blade did not. Finally, the multi blade was able to generate a 60% quality slurry where the single blade would not. However, the 60% quality with the multi blade was not stable.

Table 29: Multi Blade vs. Single Blade Comparison of (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam + Bulk Flow Enhancer) or (SIM slurry minus Antisettling) Slurry Foam Stability Results at 110°F Atmospheric Pressure

Blade Assembly	110°F Foam Quality	Time to Foam (sec)	Foam Stability Test (%lost) Baseline level	1hr	2hr	3hr	4hr	Foam Density
Multi	**18.5%**	**6**	**190**	22.1%	22.1%	22.1%	22.1%	**13.64**
Single	**18.5%**	**3**	**190**	27.4%	27.4%	27.4%	27.4%	**13.64**
Multi	25.0%	7	190	44.2%	44.2%	44.2%	44.2%	12.55
Single	25.0%	10	190	0.0%	0.0%	0.0%	0.0%	12.55
Multi	50.0%	10	190	0.0%	0.0%	0.0%	0.0%	8.37
Single	50.0%	17	210	50.5%	50.5%	50.5%	50.5%	8.37
Multi	**60.0%**	**15**	**190**	74.7%	74.7%	74.7%	74.7%	**6.7**
Single	**60.0%**	unable to foam						**6.7**

Results at 140 °F between the single blade and multi blade assemblies were similar; all foam qualities tested were unstable. The multi blade was able to generate a 60% quality slurry where the single blade would not.

Table 30: Multi Blade vs. Single Blade Comparison of (Class H + Silica Sand + Silica Four +Foamer + KCl + Retarder + Anti-Foam + Bulk Flow Enhancer) or (SIM slurry minus Antisettling) Slurry Foam Stability Results at 140°F Atmospheric Pressure

Blade Assembly	140°F Foam Quality	Time to Foam (sec)	Foam Stability Test (%lost) Baseline level	1hr	2hr	3hr	4hr	Foam Density
Multi	**18.5%**	**4**	**190**	27.4%	27.4%	27.4%	27.4%	**13.64**
Single	**18.5%**	**3**	**194**	24.7%	24.7%	24.7%	24.7%	**13.64**
Multi	25.0%	4	190	31.6%	31.6%	31.6%	31.6%	12.55
Single	25.0%	10	190	35.8%	35.8%	35.8%	35.8%	12.55
Multi	50.0%	8	190	49.5%	49.5%	49.5%	49.5%	8.37
Single	50.0%	11	210	55.2%	55.2%	55.2%	55.2%	8.37
Multi	**60.0%**	**10**	**190**	65.3%	65.3%	65.3%	65.3%	**6.7**
Single	**60.0%**	unable to foam						**6.7**

Additional comparison data is listed below in Table 31 and 32. The test results are with the SIM slurry.

Results at 110 °F between the single and multi blade assemblies are listed below in Table 28. The multi blade assembly produced all unstable foam slurries. The single blade produced stable foam slurries at 25%, 40%, and 50% quality. Again, the multi blade was able to generate a 60% quality foam, where the single blade would not.

Table 31: Multi Blade verses Single Blade Comparison of SIM Slurry Foam Stability Results at 110°F Atmospheric Pressure

Blade Assembly	110°F Foam Quality	Time to Foam (sec)	Foam Stability Test (%lost) Baseline level	1hr	2hr	3hr	4hr	Foam Density
Multi	25.0%	10	190	28.4%	28.4%	28.4%	28.4%	12.55
Single	25.0%	20	210	0.0%	0.0%	0.0%	0.0%	12.55
Multi	30.0%	12	188	41.5%	41.5%	41.5%	41.5%	11.72
Single	30.0%	18	190	37.9%	37.9%	37.9%	37.9%	11.72
Multi	40.0%	33	190	35.8%	35.8%	35.8%	35.8%	10.04
Single	40.0%	40	210	0.0%	0.0%	0.0%	0.0%	10.04
Multi	50.0%	50	190	42.1%	42.6%	42.6%	42.6%	8.37
Single	50.0%	60	190	0.0%	0.0%	0.0%	0.0%	8.37
Multi	**60.0%**	**60**	**168**	**65.5%**	**69.0%**	**69.0%**	**69.0%**	**6.7**
Single	**60.0%**	**unable to foam**						**6.7**

Results at 140°F between the single and multi blade assemblies are listed below in Table 29. The multi blade assembly produced all unstable foam slurries. The single blade produced stable foam slurries at 5% and 25% quality.

Table 32: Multi Blade verses Single Blade Comparison of SIM Slurry Foam Stability Results at 140°F Atmospheric Pressure

Blade Assembly	140°F Foam Quality	Time to Foam (sec)	Foam Stability Test (%lost) Baseline level	1hr	2hr	3hr	4hr	Foam Density
Multi	5.0%	2	190	22.1%	22.1%	22.1%	22.1%	15.9
Single	5.0%	2	250	0.0%	0.0%	0.0%	0.0%	15.9
Multi	10.0%	2	190	0.0%	10.5%	13.2%	14.2%	15.06
Single	10.0%	2	250	24.0%	28.0%	30.4%	32.0%	15.06
Multi	**18.5%**	**7**	**230**	**39.1%**	**39.1%**	**39.1%**	**39.1%**	**13.64**
Single	**18.5%**	**6**	**210**	**37.1%**	**37.1%**	**37.1%**	**37.1%**	**13.64**
Multi	20.0%	10	201	31.3%	31.3%	31.3%	31.3%	13.39
Single	20.0%	17	210	37.1%	37.1%	37.1%	37.1%	13.39
Multi	25.0%	30	206	42.2%	42.2%	42.2%	42.2%	12.55
Single	25.0%	10	210	1.0%	1.0%	1.0%	1.0%	12.55

Foam Stability of Base Oil / Cement Contamination

A study was conducted to determine the affect of the base oil on the cement system since the base oil was used as a spacer during operations. 5, 10 and 15% by volume contaminations were tested at various foam qualities at both 110°F and 140°F temperatures under atmospheric pressure as listed in Tables 33 and 34.

Addition of the base oil showed a slight instability in most cases at 110°F.

Table 33: Base Oil Contamination with H and Foamer designs at 110°F Atmospheric Pressure (Multi Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2	200	0.0%	0.0%	0.0%	0.0%	15.8	15.9	15.9	15.57
5.0%, 5% BO	4	190	2.1%	2.1%	2.1%	2.1%	15.3	15.2	16.3	15.12
5.0%, 10% BO	5	194	1.0%	1.0%	1.0%	1.0%	15.7	15.9	16.3	14.66
5.0%, 15% BO	5	187	0.0%	0.0%	0.0%	0.0%	16.1	15.8	16.2	14.21
10.0%	1	210	0.0%	0.0%	0.0%	0.0%	14.9	15	15	14.75
10%, 15% BO	5	170	0.0%	0.0%	0.0%	2.4%	0	0	0	13.44
18.5%	**2**	**182**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.5**	**13.6**	**13.6**	**13.36**
18.5%, 15% BO	**8**	**140**	**0.0%**	**0.0%**	**0.0%**	**1.4%**	**0**	**0**	**0**	**13.51**
20.0%	3	210	0.0%	0.0%	0.0%	0.0%	13.1	13.2	13.3	13.12
20.0%, 5% BO	3	190	7.4%	7.4%	7.4%	7.4%	14.9	15.3	16.2	12.79
20.0%, 10% BO	5	192	0.0%	0.0%	0.0%	0.0%	12.6	12.6	12.9	12.46
20.0%, 15% BO	4	173	0.6%	0.6%	0.6%	0.6%	12.3	12.4	12.8	12.13
25.0%	3	210	0.0%	0.0%	0.0%	0.0%	12.4	12.5	12.6	12.30
25%, 15% BO	8	170	0.0%	0.0%	0.0%	3.5%	0	0	0	11.56
30.0%	4	210	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
30.0%, 5% BO	8	193	0.0%	0.0%	0.0%	0.0%	8.8	8.8	8.7	11.23
30.0%, 10% BO	6	194	0.5%	0.5%	0.5%	0.5%	11.4	11.1	11	10.98
30.0%, 15% BO	5	186	0.0%	0.0%	0.0%	0.0%	11.3	10.5	10.8	10.31
35.0%	4	210	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
35%, 15% BO	7	142	0.0%	0.0%	0.0%	0.0%	0	0	0	10.31
40.0%	5	190	0.0%	0.0%	0.0%	0.0%	10	10	10	9.84
40.0%, 5% BO	5	170	0.0%	0.0%	0.0%	0.0%	9.4	8.9	9.2	9.67
40.0%, 10% BO	4	178	0.6%	0.6%	0.6%	0.6%	8.9	8.8	8.9	9.51
40.0%, 15% BO	3	186	0.0%	0.0%	0.0%	0.0%	9.5	8.8	8.7	9.34
45.0%	6	210	0.0%	0.0%	0.0%	0.0%	9	9.1	9.2	9.02
45%, 15% BO	7	140	0.0%	0.0%	3.6%	3.6%	0	0	0	9.06
50.0%	9	210	0.0%	0.0%	0.0%	0.0%	8	8.2	8.4	8.19
50%, 15% BO	8	182	0.0%	0.0%	0.0%	0.0%	0	0	0	8.64
55.0%	11	210	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.38
55%, 15% BO	10	158	0.0%	0.0%	0.0%	0.0%	0	0	0	7.94
60.0%	**15**	**180**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.8**	**6.56**
60%, 15% BO	**7**	**176**	**0.0%**	**0.0%**	**6.3%**	**6.3%**	**0**	**0**	**0**	**7.25**

Addition of the base oil showed little to no effect on foam qualities at 140°F.

Table 34: Base Oil Contamination with H and Foamer designs at 140°F Atmospheric Pressure (Multi Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	1	220	0.0%	0.0%	0.0%	0.0%	15.8	15.8	15.9	15.57
5.0%, 5% BO	4	190	0.0%	0.0%	0.0%	0.0%	14	14.6	14.6	15.12
5.0%, 10% BO	5	193	0.5%	0.5%	0.5%	0.5%	14.7	15.6	14.6	14.66
5.0%, 15% BO	5	193	1.6%	1.6%	1.6%	1.6%	15.4	14.6	15.1	14.21
10.0%	1	210	0.0%	0.0%	0.0%	0.0%	15	15	15	14.75
10%, 15% BO	5	170	0.0%	0.0%	0.0%	0.0%	0	0	0	13.51
18.5%	**2**	**210**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**13.6**	**13.6**	**13.6**	**13.36**
18.5%, 15% BO	**8**	**170**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0**	**0**	**0**	**12.33**
20.0%	2	210	0.0%	0.0%	0.0%	0.0%	13.1	13.2	13.4	13.12
20.0%, 5% BO	3	193	0.0%	0.0%	0.0%	0.0%	10.4	9.8	9.9	12.79
20.0%, 10% BO	5	180	0.0%	0.0%	0.0%	0.0%	11.5	10.7	10.7	12.46
20.0%, 15% BO	4	178	0.0%	0.0%	0.0%	0.0%	12.5	12.3	12	12.13
25.0%	3	210	0.0%	0.0%	0.0%	0.0%	12.2	12.3	12.4	12.30
25%, 15% BO	8	172	0.0%	0.0%	0.0%	0.0%	0	0	0	11.43
30.0%	3	210	0.0%	0.0%	0.0%	0.0%	11.6	11.7	11.7	11.48
30.0%, 5% BO	8	186	0.0%	0.0%	0.0%	0.0%	7.1	6.5	6.3	11.23
30.0%, 10% BO	6	198	0.0%	0.0%	0.0%	0.0%	9.7	9.4	9.4	10.98
30.0%, 15% BO	5	193	0.0%	0.0%	0.0%	0.0%	8.7	7.5	8.1	10.31
35.0%	4	210	0.0%	0.0%	0.0%	0.0%	10.8	10.9	10.9	10.66
35%, 15% BO	7	170	0.0%	0.0%	0.0%	0.0%	0	0	0	10.04
40.0%	5	210	0.0%	0.0%	0.0%	0.0%	10	10	10	9.84
40.0%, 5% BO	5	170	0.0%	0.0%	0.0%	0.0%	9	7.9	7.8	9.67
40.0%, 10% BO	4	187	0.0%	0.0%	0.0%	0.0%	6.9	7.4	9.5	9.51
40.0%, 15% BO	4	175	0.0%	0.0%	0.0%	0.0%	9.6	8.1	7.9	9.34
45.0%	6	210	0.0%	0.0%	0.0%	0.0%	9	9.1	9.2	9.02
45%, 15% BO	7	176	0.0%	0.0%	0.0%	0.0%	0	0	0	8.642
50.0%	7	210	0.0%	0.0%	0.0%	0.0%	8.4	8.4	8.4	8.19
50%, 15% BO	8	177	0.0%	0.0%	0.0%	0.0%	0	0	0	7.9365
55.0%	9	210	0.0%	0.0%	0.0%	0.0%	7.5	7.5	7.5	7.38
55%, 15% BO	10	169	0.0%	0.0%	14.8%	14.8%	0	0	0	7.248
60.0%	**15**	**230**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**6.7**	**6.7**	**6.7**	**6.56**
60%, 15% BO	**7**	**180**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0**	**0**	**0**	**6.551**

The next set of data is the base oil contamination results for class H cement, silica flour, silica sand, foamer, KCl, retarder, anti-foam, antisettling, and bulk flow enhancer additive at 110 °F and 140 °F at atmospheric pressure. These results are shown below in tables 35 and 36.

Table 35: Base Oil Contamination with SIM Slurry Foam Stability Results at 110°F Atmospheric Pressure (Multi Blade)

110°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
25.0%	20	210	0.0%	0.0%	0.0%	0.0%	11.8	12.1	11.7	12.55
25.0%, 5% BO	12	212	6.6%	6.6%	6.6%	6.6%				12.25
25.0%, 10% BO	11	206	6.8%	6.8%	6.8%	6.8%				11.95
25.0%, 15% BO	10	195	17.9%	17.9%	17.9%	17.9%				11.64
45.0%	50	180	0.0%	0.0%	0.0%	0.0%	10.1	9.9	9.9	9.2
45%, 15% BO	12	170	40.0%	40.0%	40.0%	40.0%				8.80
50.0%	60	190	0.0%	0.0%	0.0%	0.0%	9.8	9.9	9.7	8.37
50.0%, 5% BO	6	198	0.0%	0.0%	0.0%	0.0%				8.28
50.0%, 10% BO	9	210	1.9%	1.9%	1.9%	1.9%				8.18
50.0%, 15% BO	9	230	0.0%	0.0%	0.0%	0.0%				8.09
55.0%	55	190	42.1%	42.1%	42.1%	42.1%				7.53
55%, 15% BO	10	170	41.2%	41.2%	41.2%	41.2%				7.38
60.0%	**60**	**168**	**65.5%**	**69.0%**	**69.0%**	**69.0%**				**6.7**
60%, 15% BO	**12**	**170**	**47.1%**	**47.1%**	**47.1%**	**47.1%**				**6.67**

Table 36: Base Oil Contamination with SIM Slurry Foam Stability Results at 140°F Atmospheric Pressure (Multi Blade)

140°F		Foam Stability Test (%lost)					Density			Foam
Foam Quality	Time to Foam (sec)	Baseline level	1hr	2hr	3hr	4hr	Top	Middle	Bottom	Density
5.0%	2	250	0.0%	0.0%	0.0%	0.0%				15.9
5.0%, 5% BO	4	190	3.2%	3.2%	3.2%	3.2%				15.43
5.0%, 10% BO	4	190	3.2%	3.2%	3.2%	3.2%				14.96
5.0%, 15% BO	4	192	0.0%	0.0%	0.0%	0.0%				14.49
25.0%	10	210	1.0%	1.0%	1.0%	1.0%	10.4	11.9	14.1	12.55
25.0%, 5% BO	12	210	0.5%	0.5%	0.5%	0.5%				12.25
25.0%, 10% BO	11	196	7.1%	7.1%	7.1%	7.1%				11.95
25.0%, 15% BO	10	190	22.6%	22.6%	22.6%	22.6%				11.64
45.0%	50	180	0.0%	0.0%	0.0%	0.0%	10.4	10.2	10.3	9.2
45%, 15% BO	12	170	34.1%	34.1%	34.1%	34.1%				8.80
50.0%	60	174	0.0%	0.0%	0.0%	0.0%	10.6	10.7	10.5	8.37
50.0%, 5% BO	6	202	5.9%	5.9%	5.9%	5.9%				8.28
50.0%, 10% BO	9	210	2.4%	2.4%	2.4%	2.4%				8.18
50.0%, 15% BO	9	242	0.0%	0.0%	0.0%	0.0%				8.09
55.0%	55	210	40.5%	40.5%	40.5%	40.5%				7.53
55%, 15% BO	10	170	41.2%	41.2%	41.2%	41.2%				7.38
60.0%	**60**	**210**	**52.4%**	**52.4%**	**52.4%**	**52.4%**				**6.7**
60%, 15% BO	**12**	**170**	**57.6%**	**57.6%**	**57.6%**	**57.6%**				**6.67**

1000psi Foam Stability

Foam Stability tests were performed after foaming the slurry with 1000psi of nitrogen gas. This simulates the injection of the gas at the surface under pressure. Tests were conducted at 80°F, 110°F and 140°F for select slurries as seen in Table 37.

Table 37: 1000psi Foam Stability

Slurry Number	System	Temperature °F	Designed Density lb/gal	Target Foam Quality %	Section	Foam Quality	*Atmospheric Stability Testing Single / Multi	**Conclusions
1	SIM	80	6.70	60.0%	Top	51%	Unstable/ -	Confirmed
					Middle	na		
					Bottom	40%		
2	SIM	140	13.64	18.5%	Top	7%	Unstable/Unstable	Confirmed Both Techniques
					Middle	5%		
					Bottom	5%		
3	SIM Repeat	140	13.64	18.5%	Top	2%	Unstable/Unstable	Confirmed Both Techniques
					Middle	8%		
					Bottom	3%		
4	H and Foamer	110	6.56	60%	Top	65%	Stable / -	Confirmed
					Middle	65%		
					Bottom	66%		
5	SIM	110	12.55	25%	Top	17%	Stable/Unstable	Confirmed Multi Blade Technique
					Middle	18%		
					Bottom	7%		
6	SIM Repeat	110	12.55	25%	Top	20%	Stable/Unstable	Confirmed Multi Blade Technique
					Middle	20%		
					Bottom	8%		

*Note: Some slurries were generated with the single blade technique and others with the multi blade technique and some with both.

**Note: Confirmed means the 1000psi foam generated result matches the atmospheric stability testing result with single or multi blade.